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A Broadband, Low Noise, Integrated 340 GHz Schottky Diode Receiver

Peter J. Sobis, *Student Member, IEEE*, Niklas Wadefalk, Anders Emrich, and Jan Stake, *Senior Member, IEEE*

***Abstract*—A 340 GHz subharmonic Schottky diode mixer and a multioctave (3-17 GHz) custom LNA have been integrated to form a compact receiver front-end module, exhibiting ultra low noise with an exceptional flat response and broadband instantaneous frequency coverage. At room temperature, a receiver noise temperature of 870 K is measured at an LO drive of 1.2 mW at 170 GHz. The total DC power consumption of the LNA is below 120 mW. Measurements are in good agreement with simulations taking the mixer and LNA mismatch interaction into account.**

***Index Terms*—Submillimeter wave technology, Schottky diodes, heterodyne receivers, radiometers, subharmonic mixers, low noise amplifiers**

I. Introduction

THE next generation Earth science missions and planetary exploration missions [1,2] will rely on broadband state-of-the-art submillimeter wave heterodyne Schottky receivers. The low weight, high reliability and long operational lifetime, compared to cryogenic receiver systems [3], are the main qualities that make room temperature technology suitable for this type of applications.

The core elements of a Schottky receiver front-end are the mixer [4], most efficiently realized as a subharmonic mixer, and the IF low noise amplifier LNA [5]. In general the integration and co-optimization of critical components in the front-end receiver system can improve performance considerably, increasing bandwidth, reducing power consumption and size etc. [6-9]. For heterodyne Schottky diode based receiver systems [10-14], typically the mixer and LNA come as two physically separated units interconnected with a 50 Ω interface. This not only increases the IF loss and consequently the receiver noise, but also introduces a strong IF ripple due to the mismatch between the LNA input and the mixer's high IF impedance [15]. Consequently the effective frequency coverage and the accuracy of the instrument are reduced, motivating the integration and co-optimization of the LNA and mixer.

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P. J. Sobis is with Omnisys Instruments AB and with the Gigahertz Centre, Terahertz and Millimeter wave Laboratory, Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, SE-412 96 Göteborg, Sweden (e-mail: peter.sobis@chalmers.se).

N. Wadefalk is with the Microwave Electronics Laboratory, MC2, Chalmers University of Technology, SE-41296, Göteborg, Sweden.

J. Stake, is with the Gigahertz Centre, Terahertz and Millimetre wave Laboratory, MC2, Chalmers University of Technology, SE-41296, Göteborg, Sweden.

A. Emrich is with Omnisys Instruments AB, August Barks gata 6B, SE-421 32 V.F., Sweden.

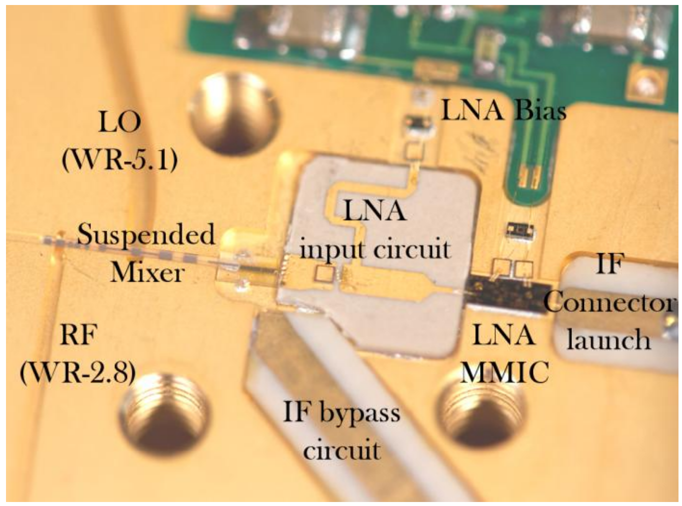

Fig.1. Photo of the receiver split block assembly showing the suspended subharmonic DSB mixer and MMIC IF LNA with accompanying sub-circuits.

In this paper the advantages of LNA and mixer integration are shown, by a first time demonstration of state-of-the-art performance, in terms of low receiver noise, low ripple and broad instantaneous frequency coverage, of an integrated receiver operating in the 320-360 GHz frequency band. Furthermore, a simple method based on IF characterization of the mixer IF response using a bypass IF circuit and co-simulation of this data with the LNA is presented, allowing for accurate prediction of the receiver noise response and further co-optimization of the mixer and LNA combined response.

II. Design

The integrated front-end module, see Fig. 1, was based on a subharmonic Schottky diode mixer, as described in [16] with a

RF center frequency of around 340 GHz, and on a multioctave 4-16 GHz custom MMIC hybrid LNA design developed at Chalmers University of Technology. The LNA had an equivalent minimum input noise temperature ranging from 30 K to 80 K with about 30 dB of gain within the band of operation, see Fig. 2. The mixer used an anti-parallel Schottky diode chip, supplied by Virginia Diodes Inc.. The surface channel planar anti-parallel diodes [17] had a typical pad to pad capacitance of 4 fF, a series resistance of 10 Ohm, ideality factor of about 1.1 and a total chip capacitance of 10 fF. The receiver module housing was of E-plane split block type and measured 24 mm by 27 mm by 20 mm (W x L x H). It accommodated both the RF and LO waveguide interfaces, as well as the mixer, LNA and IF circuits including bias circuitry and the IF connector launch. Thereto a parallel IF channel was also included in the block, allowing for separate testing of the mixer conversion loss, noise and IF impedance, by simply re-routing a wirebond connection.

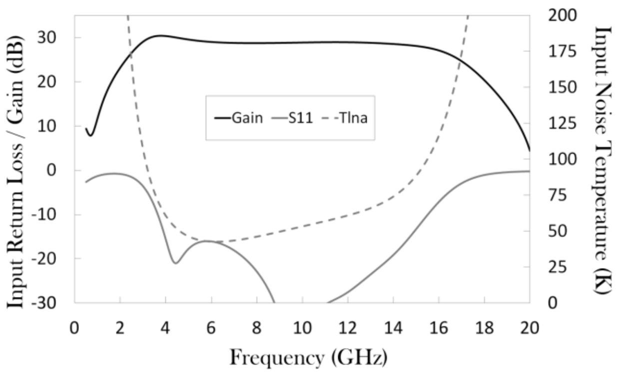

Fig. 2. Gain, input return loss and input noise data of the LNA (50 Ω).

III. Measurement Setup

Two receiver modules were assembled and tested in a semi-automated hot/cold measurement setup described in [16]. A corrugated WR-2.8 horn from Radiometer Physics GmbH was used together with a broadband active LO multiplier source module consisting of an active W-band x6 multiplier from Omnisys and a broadband 170 GHz Schottky varactor doubler from Chalmers, see Fig. 3.

IV. Results and Discussion

Both receivers showed an optimum noise performance at an LO power of around 1.2 mW, which was measured by connecting an Erickson PM4 power meter directly to the doubler LO flange.

By the use of an IF bypass circuit, the mixer noise and conversion loss could be estimated. This was done by using a 3 dB attenuator and a coaxially packaged LNA module based on the same design that was incorporated to the integrated receiver. The complex reflection coefficient of the mixer IF port was characterized up to 20 GHz using a VNA, allowing for detailed modeling of the mixer diode IF impedance and circuit assembly. The mixer conversion loss and noise was estimated in the 6-8 GHz IF range, at which the mixer IF port impedance was close to 50 Ohm and effect of IF ripple

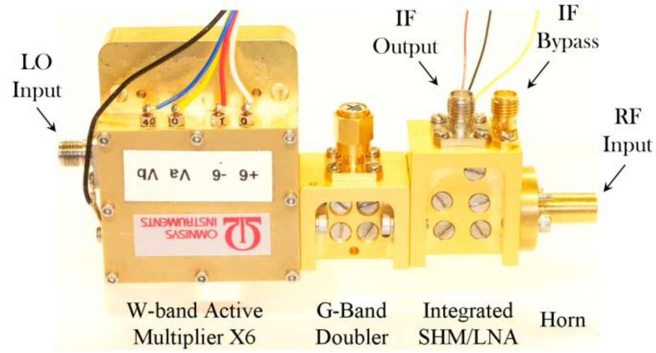

Fig. 3. Photo of the front end receiver module including the LO multiplier chain and corrugated horn as used in the test setup.

minimized, to approximately 6 dB (DSB) and 780 K (DSB) respectively. For the integrated receiver the estimated mixer noise at the receiver noise minimum point at around 3.5 GHz IF, using T_{min} equal to 33 K for the LNA input noise and 9 dB for the mixer conversion loss, was found to be about 760 K. The diode IF impedance was found to be around 200 Ω at an 1.2 mW LO drive, varying from 130 Ω at high drive to 270 Ω at low drive.

Based on the mixer characterization together with a detailed LNA model and detailed 3D-EM modeling of the packaged mixer circuit IF response, the full receiver noise response can be simulated. The receiver noise was found to strongly depend on the mismatch to the mixer high IF impedance and distance of the LNA to the mixer diode, increasing the noise level and ripple amplitude and the ripple periodicity respectively.

The measured receiver noise of two receiver modules is presented in Fig. 4 together with simulations of the minimum receiver noise based on the minimum input noise temperature T_{min} of the LNA, and of the receiver noise based on the performance of the coaxial LNA module, assuming the mixer IF port impedance to be 50 Ω. The two modules have very similar responses showing good repeatability. A clear reduction in bandwidth with a slow and small ripple is noticed. Also a noticeable increase of the receiver noise in the

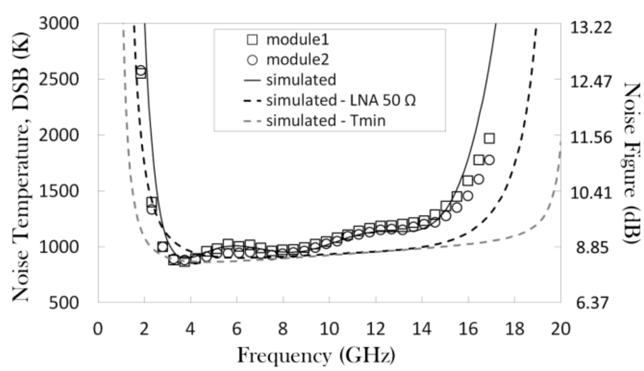

Fig.4. Measured receiver DSB noise temperature versus IF frequency for two assembled integrated receiver modules compared with simulations of the receiver noise taking the mixer and LNA interaction into account as well as estimates of the minimum receiver noise assuming a 50 Ω mixer IF impedance in the first case and T_{min} for the LNA for the second case. The mixer conversion loss and noise are assumed to be constant.

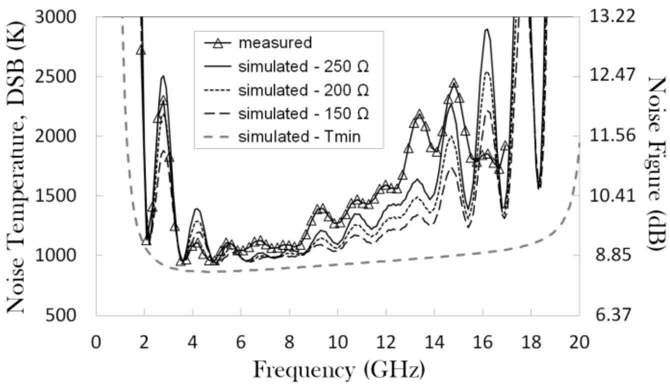

Fig.5. Measured and simulated receiver DSB noise temperature versus IF frequency using an external LNA together with simulations of the receiver noise for different mixer IF impedances.

higher end of the band is shown compared to the case the LNA and mixers IF port had been matched to 50 Ω. The ripple minima in the lower part of the IF band also coincide well with the ideal receiver noise response assuming the minimum noise temperature T_{min} for the LNA and matched conditions.

A constant mixer conversion loss of 6 dB (DSB), a mixer noise of 770 K (DSB) and a mixer IF impedance of 200 Ω was used in the simulations. As a fixed LO frequency is used, close to the design center frequency, and due to the relative broad RF frequency coverage of the mixer, a relatively small variation in the mixer DSB conversion loss and DSB noise could be expected. In Fig. 5 measurements and simulations of the receiver using the external LNA are plotted, for different diode impedances. The main sources for deviations between measurements and simulations are thought to come from the assembly, mainly from mismatches in the coaxial connector interfaces of the LNA and mixer packages, which were not included in the simulations.

V. Conclusion

A compact receiver front-end module with ultra broadband and flat noise characteristics has been demonstrated, showing the advantage of integrating the mixer and LNA in the same package. By co-simulation of the LNA and mixer IF circuit, using a constant mixer noise, conversion loss and diode IF impedance based on measured results, a good prediction of the receiver noise characteristic was achieved. The noise response of the integrated receiver was found to be largely affected by the mixer IF impedance in combination with the mixer and LNA interaction. Thus for instruments requiring optimum noise performance over large instantaneous IF bandwidths, co-optimization of the mixer and LNA noise combined response is found to be necessary.

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